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MAUNA LOA OBSERVATORY

for high altitude research

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DETROIT

A UNIQUE high-altitude observatory on the slope of the Hawaiian volcano, Mauna Loa, was dedicated on June 28 for joint use by the National Bureau of Standards and the U. S. Weather Bureau. Located at a height of 11,134 feet in the tropics, where the upper atmosphere is very clear and usually of low moisture content, the new observatory offers special advantages for many types of astronomical and upper-air studies. It will make possible continuous observation of atmospheric phenomena with manned instruments in place of the unmanned meteorological balloons that have been used for the most part in high-altitude work.

The dedication ceremonies were arranged by R. L. Fox of the Weather Bureau, and J. B. Cox, president of the Geophysical Society of Hawaii, acted as master of ceremonies. After introductory remarks by Governor S. W. King of Hawaii, J. W. Steiner of the Weather Bureau gave some highlights on the new facility. Ralph Stair and C. C. Kiess of NBS then spoke on research potentials of the observatory and its use in studying the planet Mars. Prof. W. B. Steiger of the University of Hawaii commented on the importance of the observatory to geophysics, and Mr. Fox discussed the past, present, and future of the observatory.

The new observatory is expected to provide valuable data in a variety of fields. Its advantages as a high-altitude observatory are due largely to the fact that it is situated well above the bulk of the dust and moisture contained in the earth's atmosphere. At the latitude of Hawaii a "trade wind inversion layer" usually traps the dust and moisture below about 8,000 feet.

Other important advantages of the Mauna Loa Observatory are its ready accessibility and relatively warm climate. Most of the other comparable observatory sites are buried in snow during winter and part of the summer. Also, the Mauna Loa Observatory has the required altitude without the ruggedness that imparts turbulence to the surrounding air, and it is situated at a key point for studying the huge air masses of the tropics.

The chief research results to be expected from the observatory are improved long-range weather forecasting and greater knowledge of solar and atmospheric radiation. Because the air masses of the Pacific are responsible for much of the weather that occurs in other parts of the world, data on these air masses may make it possible to forecast conditions in distant places.

There is some evidence that the ozone content of the lower atmosphere in the tropics is associated with the formation of the large low-pressure areas that produce typhoons. Continuous measurement of atmospheric ozone may thus be of assistance in forecasting typhoons in advance.

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High-altitude observatory on the slope of Mauna Loa. The platform in the foreground and the tower at right are used in making observations.

The observatory also offers possibilities for study of cosmic rays, total solar radiation, snow crystals, air glows, and possibly radioactive fallout. In July, C. C. Kiess and C. H. Corliss of NBS began a study of the moisture content of the planet Mars under the auspicies of the National Geographic Society. They used spectroscopic techniques to investigate the light reflected to the earth from Mars. The advantageous location of the Mauna Loa observatory made it possible to reduce the effect of the earth's atmosphere on the planet's spectrum.

During the coming year Ralph Stair of NBS expects to begin a study at Mauna Loa on the distribution of the spectral energy from the sun. Such information will be of value in determining the effect of the sun's rays in connection with high-altitude equipment, space flights, and manmade satellites. This work will also furnish data on the solar constant and information on solar intensities that may be useful in many fields.

The observatory is a concrete-block structure costing $25,000, and is situated about 2,500 feet below the summit of the mountain. The building contains five rooms in addition to a tower and a broad open platform for observational use. Present accommodations permit the use of the buildings by a maximum of six observers at any one time.

A smaller structure was built at the summit in 1951–52, but the limited observations that were taken there were discontinued in 1954 because of the extreme difficulty of traversing the trail to the summit. It is hoped that at some future time a functional unit can be established at the summit.

Drawing of Mauna Loa volcano, showing the new 2-mile-high observatory about 2,500 ft below the summit. In this latitude moisture and dust (indicated by dots) are usually trapped below about 8,000 ft.

EVALUATION OF TEST METHODS BY THE SENSITIVITY CRITERION

PRECISION and accuracy are the criteria by which the merit of a test is usually evaluated. A good test method is generally expected to give results that are highly reproducible (precise) and as close to the "real" value as possible (accurate). Another criterion, usually called "sensitivity," has been used in the evaluation of test equipment such as balances and electronic meters and refers to the ratio of the change in the response to the change in the quantity studied.[1]

NBS has introduced a more generalized form of the sensitivity concept which is useful as a widely applicable criterion for instruments and methods of test. Underlying this generalized sensitivity concept, developed by J. Mandel and R. D. Stiehler of the Bureau staff, is the requirement that a satisfactory method be both reproducible and responsive to changes in the objects measured.[2] This concept, referred to as the "sensitivity criterion," has recently been applied to the comparison of two paper smoothness testers by T. W. Lashof of the Bureau's paper laboratory. A complex relationship was found between the two instruments which might have been misleading had the usual criteria of merit been used.[3]

Measuring paper smoothness on two different types of instruments. In the instrument at left, a fixed volume of air under a specified pressure flows between a flat surface and the paper. The time required for the airflow, indicated by the drop of the mercury column, is recorded on a stopwatch. Rate of airflow in instrument B is measured by the position of a bob in one of the three columns of the precision flowmeter. A comparison of test results, using the NBS sensitivity criterion, indicates a close but complex relationship between the two instruments.

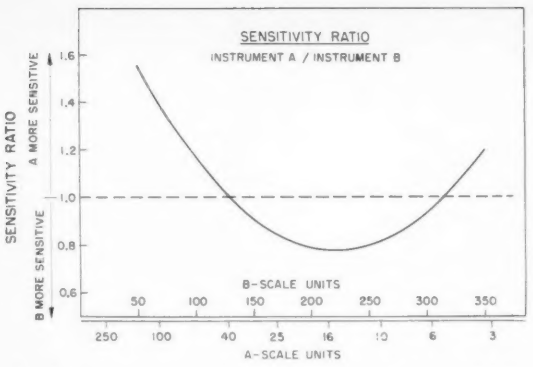
In the generalized sensitivity concept, reproducibility is measured by standard deviation, and responsiveness is measured by the ratio of the change in the response to the change in the property studied. Thus the Bureau defines the sensitivity of a method A as $(\Delta A/\Delta Q)/\sigma_A$, where Q is the property studied, A the reading by the given method of measurement, and σ_A the standard deviation of method A. In the comparison of two alternate methods of test, A and B, the Bureau sensitivity concept leads to the ratio of the sensitivities $(\Delta A/\Delta Q)/\sigma_A$ and $(\Delta B/\Delta Q)/\sigma_B$ as the criterion by which the better method can be selected. The ratio is thus $(\Delta A/\sigma_A)/(\Delta B/\sigma_B)$ or $(\Delta A/\Delta B)/(\sigma_A/\sigma_B)$, and involves determination of the two standard deviations, σ_A and σ_B, and the slope $\Delta A/\Delta B$ of the relationship between A and B.

There are many cases where alternate methods of test are available. For example, the wear of paper currency might be measured either by changes in air-permeability or by changes in stiffness. As a bill wears, the fibers tend to separate and break, thus allowing air to pass through the bill more easily and, simultaneously, making the bill less stiff. If it is assumed that methods testing either air-permeability or stiffness are adequate measures of wear, the relative merit of the two tests may be compared by the ratio of their sensitivities. The sensitivity criterion should be useful in cases where there is no absolute standard of comparison and no simple proportional relationship between the results obtained by two or more given methods.

The two instruments that the Bureau compared by means of the sensitivity criterion give smoothness values by measuring resistance to airflow between a paper surface and an optically flat surface pressed against it. In the first instrument, or method A, a fixed volume of air under a specific pressure flows between the flat surface and paper. The time required for this airflow, indicated by the drop of a column of mercury, is recorded on a stopwatch. The rate of airflow in the second instrument, or method B, is measured by the position of a bob in one of three conically-shaped columns of a precision flowmeter.

The experiment consisted essentially of two parts: (1) a study of the reproducibility of each of the two instruments, giving σ_A and σ_B; and (2) a study of the relationship between smoothness values yielded by the two instruments, giving the slope $\Delta A/\Delta B$. The Bureau found that while the standard deviation of method B was essentially constant for all smoothness values, the standard deviation of method A increased approximately in proportion to the smoothness value. If this difference in behavior is ignored, serious misinterpretations can arise in the comparison of the two methods. The sensitivity criterion takes this into account.

The second part of the experiment showed that for all but the very smooth papers, the values obtained by the two instruments are closely related to each other. However, the relationship is quite complicated and would not have been reflected in an evaluation based on



Sensitivity ratio of two paper smoothness testers was determined over the entire range of smoothness values that can be measured. Instrument B is superior in the middle region, but less sensitive than A at both extremes. Additional factors, such as economy and speed of operation, may be considered when choosing a method for a specific determination.

the usual criteria of comparison. The sensitivity criterion reflects this relationship because it involves the slope of the curve at each of its points.

From the data obtained in this experiment, the ratio of the sensitivities of the two instruments was determined over the entire range of smoothness values that can be measured. Instrument B was found to be superior in the middle region, but somewhat less sensitive than instrument A at both extremes. However, the sensitivity criterion considers only the technical merit of methods A and B. From the broader, economic viewpoint, method B may be more desirable, even at the extremes where it is technically less sensitive, because it requires only one fifth of the time required by method A. Thus the loss in sensitivity of method B at the extremes can be effectively compensated by testing a larger number of specimens.

It is reasonable to expect that the sensitivity criterion can be used to advantage in a great variety of studies involving either the comparison of methods of test or the determination of optimum operating conditions for a given method.

[1] Terminology for describing the performance of analytical and other precise balances—1954 report and recommendations of the Committee on Balances and Weights, *by L. B. Macurdy, H. K. Alber, A. A. Benedetti-Pichler, Hugh Carmichael, A. H. Corwin, R. M. Fowler, E. W. D. Huffman, P. L. Kirk, and T. W. Lashof, Anal. Chem.* **26**, *1190 (1954)*.

[2] *For further technical details, see* Sensitivity—a criterion for the comparison of methods of test, *by J. Mandel and R. D. Stiehler, J. Research NBS* **53**, *155 (1954) RP2527.*

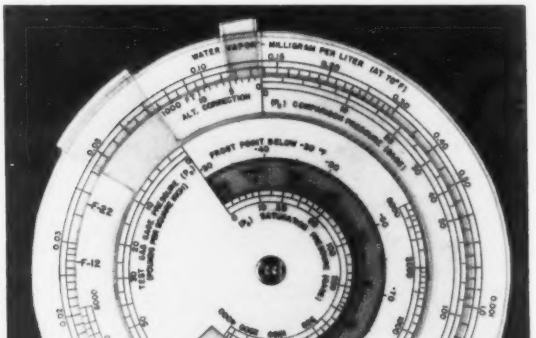
[3] *For further technical details, see* Use of the sensitivity criterion for the comparison of the Bekk and Sheffield smoothness testers, *by T. W. Lashof, J. Mandel, and V. Worthington, Tappi* **39**, *532 (1956)*.

COMPUTING DEVICE FOR WATER CONTENT OF GASES

A SIMPLE hand computer for rapidly calculating the water content of gases has been developed by A. W. Diniak and E. R. Weaver of the gas chemistry laboratory. Of the circular slide rule type, the new computer [1] is faster, more accurate and less expensive than previous devices for this purpose. In connection with the Bureau's method [2] for determining moisture in gases, the computer has been used by the armed services to calculate the water content of aviator's oxygen, rocket fuels, and fire-extinguisher gases. The device should also save considerable time in such industrial applications as the determination of refrigerating system characteristics and control of moisture in inert and reducing gases.

The computer is designed primarily to calculate water content and dewpoint of gases from observations of the electrical conduction of a hygroscopic film as it absorbs water vapor. Corrections are automatically made for deviations from the ideal laws relating to vapors in gases. Such deviations are independent of measurement methods but nevertheless affect computations in which they have usually been ignored.

The computer consists of a plastic base disk about 4 in. in diameter and two smaller rotating disks marked with appropriate temperature, pressure, and altitude scales. Additional scales may be read through a plastic window in the top disk, thus extending the scope and improving the readability of the device. A logarithmic scale on the rim of the base disk resembles that of an ordinary slide rule and may be used for a number of computations involving conversion of units.



[1] *For further technical details, see* A new computer for calculating the water content of gases, *by A. W. Diniak, and E. R. Weaver, J. Research NBS* **56**, *269 (1956) RP2674.*

[2] *See* Measurement of water in gases by electrical conduction in a film of hygroscopic material and use of pressure changes in calibration, *by E. R. Weaver and R. Riley, J. Research NBS* **40**, *169 (1948) RP1865; also* Moisture determination by electrolytic film, *NBS Tech. News Bull.* **32**, *13 (February 1948)*.

GAGE BLOCK RESEARCH CONFERENCE

TWENTY-ONE representatives of major industrial firms attended a Conference on Gage Block Research held at the Bureau on August 21. Purpose of the Conference was to report progress on a research project directed toward increased accuracy in industrial gage-block calibration. Ten of the corporations represented at the Conference are contributing funds to the project.

Highlight of the program was the demonstration of practical equipment for comparing gage-block lengths to the nearest ten-millionth of an inch. Designed by Theodore R. Young and James B. Saunders of the NBS staff, the instrument is an interferometric comparator [1] of extremely high precision. Its development represents an important step toward the ultimate goal of the gage-block project, which seeks to provide means for the Bureau to calibrate industrial master gage blocks on a routine basis to an accuracy of 1 part in 10 million.

The Bureau now certifies master gage blocks to an accuracy of one part in a million, that is, to the nearest millionth of an inch for inch-long blocks. However, as mechanized industry becomes steadily more complex, the dimensional tolerances that can be permitted in machine parts is continually decreasing. Today tolerances of 1 part in 10,000 are quite common and demands for tolerances of a few parts in 100,000 are developing in several areas—notably the guided-missile, jet-aircraft, and refrigeration industries. This, in turn, requires greater precision in the manufacture of machine tools, such as grinders, for making these parts. Makers of antifriction bearings, used in grinders and other machine tools, have therefore requested the Bureau to develop procedures for calibrating their master gage blocks to a precision of 1 part in 10 million.

Because of the extreme importance of this work, Congress has provided a substantial increase in the Bureau's appropriation, specifically requesting increased effort on this project. The 10 industrial firms have given an additional $19,500 per year for 3 years so that the Bureau may carry out the necessary research as rapidly as possible.

Objectives of the project are twofold: (1) to develop instrumentation and methods that will enable the Bureau to certify master gage blocks to the nearest ten-millionth of an inch; and (2) to develop more stable alloys for gage blocks so that measured lengths will not change appreciably with time. In connection with the latter phase, the NBS Metallurgy Division is now evaluating gage-block materials for dimensional stability, wear and corrosion resistance, and thermal expansion.

A major problem yet to be solved is the development of means for the absolute measurement—to the nearest ten-millionth of an inch—of the primary standard gage blocks with which the Bureau compares industry's master gage blocks. This measurement will require extremely accurate control of temperature, air pressure, and other conditions.

The visitors to the Conference consisted principally of representatives of the sponsoring firms. They were welcomed to the Bureau by Dr. Allen V. Astin, NBS Director. Next, Irvine C. Gardner, Chief of the Optics and Metrology Division, and James I. Hoffman, Chief

of the Metallurgy Division, discussed, respectively, the instrumentation and metallurgical phases of the program. The guests then visited the laboratories in which the research is being conducted, and witnessed a demonstration of the gage-block comparator (insert above) by Messrs. Young and Saunders. They also saw equipment in the Metallurgy Division to be used in heat-treatment and stabilization studies of the blocks. This was demonstrated by Thomas G. Digges and Melvin R. Meyerson.

The manufacturing firms supporting the Bureau's gage-block research program are E. I. du Pont de Nemours & Co., Greenfield Tap & Die Corp., Hughes Aircraft Co., The Taft-Peirce Manufacturing Co., The Timken Roller Bearing Co., The Van Keuren Co., The Sheffield Corp., The DoAll Co., Dearborn Gage Co., and Pratt & Whitney Co., Inc.

[1] *An article on this instrument will appear in an early issue of the Technical News Bulletin.*

HIGH-PURITY BARIUM TITANATE

BARIUM TITANATE is now being used extensively in electronic devices because of its desirable dielectric and piezoelectric properties. Important applications of this ceramic include high-capacity miniature condensers, ultrasonic transmitters, and transducers for sensing devices in accelerometers, sound detectors, velocimeters, and strain and pressure gages. However in spite of its wide use, the relationship between composition and electrical characteristics of barium titanate has not been fully worked out.

To aid in the solution of this problem, the Bureau recently developed a method [1] for preparing very-high-purity barium titanate in which the mole ratio of barium to titanium is exactly unity. Using the pure material, ceramic engineers should now be able to determine systematically the effect of various minor components on the electrical properties of barium titanate and to arrive at a reproducible composition having the most desirable electrical characterictics.

The procedure for preparation was devised by W. S. Clabaugh, E. M. Swiggard, and Raleigh Gilchrist of the Bureau's inorganic chemistry laboratory, working under the sponsorship of the Diamond Ordnance Fuze Laboratories, Department of the Army. The method involves, first, preparation of the double oxalate tetrahydrate, $BaTiO(C_2O_4)_2{\cdot}4H_2O$. This compound is then ignited, yielding a pure barium titanate containing equal molar proportions of barium and titanium.

The oxalate is prepared by very slowly adding an aqueous solution of titanium tetrachloride and barium chloride to a hot solution of oxalic acid. The titanium tetrachloride and barium chloride are in nearly equimolar proportion but with barium in slight excess, while the amount of oxalic acid is about 10 percent more than the reaction requires. The purpose of the excess barium and oxalate is to minimize competing reactions that might result in formation of insoluble partially hydrolyzed compounds of titanium.

While the solutions are being added, the oxalic acid solution is continuously heated at 80° C. Eventually a dense crystalline precipitate of $BaTiO(C_2O_4)_2{\cdot}4H_2O$ is formed. This substance can then be converted to barium titanate by heating in a furnace at 900° C.

The titanium tetrachloride solution is made by adding the highly purified tetrachloride, drop by drop, to rapidly stirred distilled water cooled in an ice bath. This procedure prevents formation of hydrolyzed titanium compounds. The exact titanium content of the solution must then be determined so that the quantities of barium chloride and oxalic acid to be used can be based on this value.

Precipitation of barium titanyl oxalate tetrahydrate is the first step in the NBS method for preparing high-purity barium titanate. The precipitate is obtained by slowly adding an aqueous solution of titanium tetrachloride and barium chloride to a hot solution of oxalic acid. The oxalate is then ignited in a furnace to give barium titanate.

[1] *For further technical details, see* Preparation of barium titanyl oxalate tetrahydrate for conversion to barium titanate of high purity, *by W. Stanley Clabaugh, Edward M. Swiggard, and Raleigh Gilchrist, J. Research NBS* **56**, *289 (1956) RP2677.*

Dental Comparator

AN instrument has been developed for determining the accuracy and dimensional stability of artificial dentures. A pantographic type of comparator, the instrument measures the surface contours of two dental impressions or dentures and indicates dimensional differences to an accurary of ± 0.002 in. or better. The comparator can also be used to measure dimensions of both hard and elastic impressions and models of oral structures. Primarily a research tool, the instrument was developed by Commander N. W. Rupp, NBS guest worker from the U. S. Navy; M. E. Lawson, Jr., American Dental Association research associate at the Bureau; and George Dickson and W. T. Sweeney of NBS.[1]

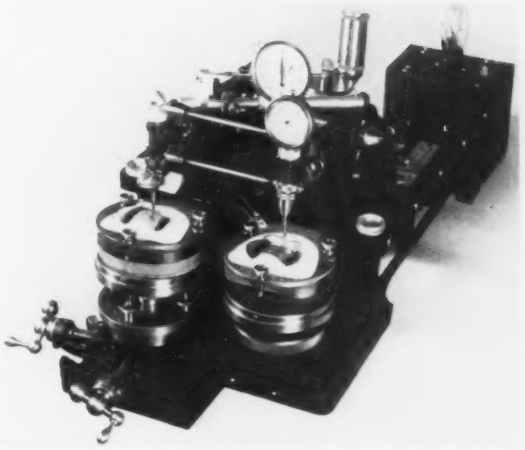
In evaluating materials and techniques for making artificial dentures, two of the most important considerations are the accuracy with which the finished denture fits and its dimensional stability during service. In the past, limited information on accuracy has been obtained by observation of the fit of a denture on a plaster model and by measurements in a horizontal plane between reference marks placed on a denture. However, such measurements do not give sufficient information on changes in shape. Capable of detailed and precise measurements, the dental comparator should greatly facilitate investigations of the factors that produce dimensionally stable and therefore more comfortable, durable, and efficient dentures.

The comparator, essentially a means of positioning two dentures and tracing their contours, is built on the framework of a Kern Dentagraph, designed and manufactured by G. R. Kern. The dentures are placed on adjustable platforms below two pointers attached to a movable framework. The framework is pantographic and has two arms 9 in. long that pivot from the ends of a 7-in. "fixed" rod. The arms are hinged at their movable ends to a rod the same length as the fixed rod, so as to form a parallelogram. This arrangement allows pointers extending below the moving corners to describe duplicate curves in space. Thus a contour traced by the guide pointer is duplicated by the indicator pointer. Dimensional differences are shown on a sensitive dial gage connected to the indicator pointer.

In practice, the fixed rod is mounted on tracks so that it can be moved forward or backward. It can be locked into place at 15 locations so that the contours of as many pairs of cross sections may be compared. A second dial indicator mounted across a diagonal of the parallelogram measures the lateral movement of the pointers between two readings of the same contour.

Several adjustments permit precise alinement of the dentures: a jackscrew raises and lowers the platform under the indicator pointer, and a series of screws provides for alinement on the second platform. After the dentures are fastened to the platforms, they are alined by adjusting the relationship of benchmarks placed in the impression and reproduced in the dentures.

The guide pointer is then lowered to the master impression, the exact moment of contact being indicated by an electronic device that turns off a light. The guide is next moved across the master impression, following the contour of a vertical cross section. The indicator pointer follows along, maintaining contact with the second denture even though the contour it follows is not identical to that described by the guide pointer. It maintains contact by shortening or lengthening, and the amount and direction of this vertical movement is registered on the dial gage. Thus any difference in height at similar positions on two impressions is measured and can be recorded.



Dental comparator determines the accuracy of the denture at right by comparison to the master impression from which it was made. As the guide pointer moves over a vertical cross section, any contour differences are detected by the pointer at right and indicated on the dial gage above it. Second dial gage, affixed to a diagonal of the pantograph, indicates any lateral movement.

The vertical indicator was calibrated using millimeter gage blocks placed on the platform below it. Each comparator reading was within 0.0005 in. of the calculated value for that reading. Statistical analysis of a series of remountings shows that the standard deviation of experimental error within a single mount is only 0.001 in.; when differences due to remounting at different positions are included, a standard deviation of 0.0018 in. is obtained.

The comparator has been used at the Bureau and by dental units of the Navy and Air Force to compare dentures made of a number of materials and cured by several processing techniques. A study is planned that will use the comparator to determine the accuracy and reproducibility of different methods for taking impressions of oral structures. It may also be possible to study the growth or recession of oral structures by measurements with the comparator on a series of casts made over a period of time.

[1] *For further technical details, see* A method for determining the mucosal surface contours of impressions, casts, and dentures, *by N. W. Rupp, G. Dickson, M. E. Lawson, Jr., and W. T. Sweeney, J. Am. Dental Assoc. (in press).*

PENETRATION AND DIFFUSION OF GAMMA RA

IN THE COURSE of several years of intensive research, the National Bureau of Standards has developed systematic methods [1] for solving a great many of the radiation penetration problems associated with nuclear power and propulsion reactors, radiation fallout, and medical uses of radiation. Starting on a small scale in 1948, the program has rapidly broadened as a series of advances in theory and computational technique have extended the range of problems that could be treated.

Thus, the Bureau is now playing a major role in research on radiation penetration and diffusion. To a large extent, the program is coordinated with those of other governmental and private institutions concerned with radiation. Close liaison is maintained, for example, with the Shielding Group at the Oak Ridge National Laboratory, and Bureau staff members frequently consult with personnel of other branches of the AEC, especially its Division of Biology and Medicine. Close relations have also been established with the Federal Civil Defense Administration, whose particular needs have provided specific problems for solution. In addition, regular contact with exchange of data is maintained with university and other laboratories working on related research and with private firms engaged in reactor development.

Although concerned with ionizing radiations of all kinds, the program thus far has dealt principally with gamma rays. The study as a whole is under the direction of U. Fano, Chief of the NBS Nuclear Physics Section, and is supported by the Atomic Energy Commission, the Office of Naval Research, the Navy Bureau of Ships, and the National Bureau of Standards.

Major attention has been given to gamma-ray photons in the energy range, 0.1 to 10 Mev, which is of primary interest in shielding problems. Although most of the work has dealt with mathematical theory and computational methods, a number of experiments have been performed, partly to verify calculations and partly to provide suggestions for fruitful theoretical approaches. Also, the available experimental data on the subject were collected, analyzed, and tabulated in order to provide input data for the calculations.

In the study of propagation in infinite uniform media, L. V. Spencer and U. Fano have developed the method of polynomial fitting by moments for calculating the penetration of gamma rays to moderate depths,[2] while the problems of deeper penetration have been clarified by the theoretical researches of U. Fano.[3] These results are adaptable to automatic computation, and with them pilot and large-scale calculations have been carried out for a wide variety of special problems. In many of these calculations, the Bureau has worked in close collaboration with Nuclear Development Associates, Inc. The problems were calculated on SEAC, the NBS automatic computer, using codes prepared by the Bureau's computation laboratory.

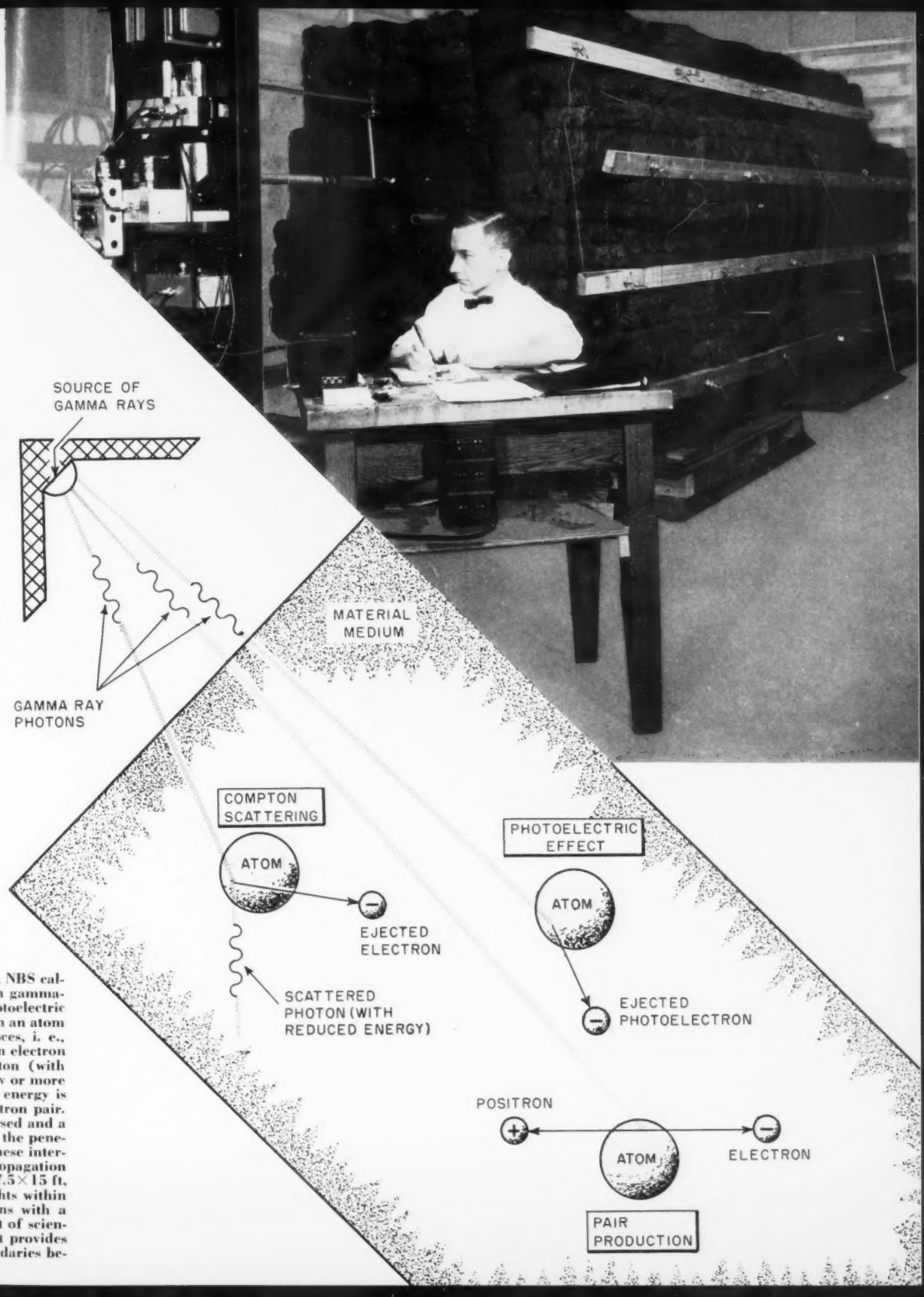
Recently the more difficult problems of penetration in nonuniform media and, in particular, the effects near a boundary between two different media, have been studied with considerable success. Both theoretical analysis and Monte Carlo experiments with automatic computers have been used. M. J. Berger has played a leading part in the Monte Carlo work.[4] More and more attention, also, is being given to research on the penetration and diffusion of high-energy electrons and neutrons. It has been found that many of the methods developed for gamma rays can also be adapted to these other forms of radiation.

The General Problem

Given a distribution of radiation sources within a material, the general problem of penetration is to determine the intensity and spectrum of the radiation that flows in each direction at each point of the material. It might seem that practical penetration problems, such as shielding design, could be solved experimentally with the help of a radiation source, several thicknesses of absorbent materials, and a radiation detector. In the past this has often been attempted, but it proved necessary to perform large-scale experiments of an engineering character whose results could not be extrapolated to different conditions. The difficulties arise because the manner of propagation of radiation depends on so many variable factors—the different kinds of interaction with the medium, the energy spectrum and directional distribution of the radiation, and the density, atomic weight, and geometry of the medium.

When gamma-ray photons traverse a medium, any of several different "elementary" processes may take place. A photon may be absorbed completely, its energy being used to eject an electron from an atom

In studying the penetration of 0.1 to 10 Mev gamma ra atter, N culations take account of the three elementary interact tween g ray photons and the medium, as shown in schematic figu photoe absorption, the energy of the photon is used to eject an el from a of the medium; later the atom recaptures an electron fluoresces emits a photon. In Compton scattering, the photon inte with an e in a process analogous to particle collision, the electr photon reduced energy) going off in different directions. Phot 1 Mev o may interact with electrostatic fields within an atom. hoton en then converted into the mass and kinetic energy of an e-positro When the positron recombines with an electron, the pro reverse new photon is produced. The mathematical problem is mpute th tration of gamma rays on the basis of the probabilities which thes actions occur. *Upper right:* An NBS experiment on ga y propa in steel wool near a boundary with steel. The steel-wool 5×7.5 rests on a steel plate. Radioactive cobalt is placed at heights the mass and the radiation intensity is measured at ositions scintillation detector inserted into a pipe (one is protru left o tist's head) running lengthwise through the mass. The ment p a check on Monte Carlo calculations of radiation behavio ounda tween different media.



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To study behavior of gamma rays near the boundary between two media, scientist inserts a scintillation detector into pipe (right) that passes through the steel-wool mass. Detector head consists of anthracene crystal, photomultiplier, and preamplifier. The tube (left) attached to detector head contains a cable that carries the preamplifier output to further amplifiers and integrating circuits. When detector head is not present in a pipe, the latter is filled with steel wool in order not to disturb the approximate uniformity of the medium.

(photoelectric effect); a part of the photon's energy may be used to eject an electron, while the photon goes off in a new direction with diminished energy (Compton scattering); or the photon (if its energy is greater than 1 Mev) may disappear, to be replaced by an electron-positron pair. These three elementary processes are, in fact, the dominating factors in the propagation of gamma rays in the range 0.1 to 10 Mev. At the lower end of the range, a minor contribution from Rayleigh scattering must be taken into account. At photon energies above 15 Mev, neutrons may be ejected from nuclei; and at energies above 150 Mev, photons begin to interact with intranuclear fields, giving rise to mesons in a process analogous to pair-production.

The total effect of all processes that either absorb photons outright or that deflect them from their original paths is measured in the so-called "narrow-beam" experiment. Here a source of monoenergetic gamma rays is channeled by slits in heavy shielding into a narrow parallel beam which passes through a layer of absorbing material to a gamma-ray detector. The beam must be narrow enough to prevent once-scattered photons from reaching the detector, and the absorbing layer must be sufficiently thin so that there is practically no chance that photons deflected out of the beam will be deflected back to the detector by further interactions.

Under the conditions of the narrow-beam experiment, the probability, p, that a photon will penetrate a distance x follows an exponential law: $p = \exp(-\mu x)$, where μ (called the "attenuation coefficient") is the probability that an interaction will occur in traversing unit distance. The smaller the value of μ, the greater is the penetrating power of the radiation. The distance, $1/\mu$, can be interpreted as the mean free path of a photon, i. e., the average distance traveled between interactions.

Using the simple exponential law, one can calculate how much of the primary radiation reaches a given point directly from the source. In addition to this, however, "secondary" radiation is also present. This consists largely of photons that have been scattered several times, arriving by a roundabout route; photons emitted by atoms from which electrons have been ejected (fluorescence); X-rays (bremsstrahlung) produced when ejected electrons are slowed down by the medium; and annihilation radiation produced when positrons recombine with electrons.

To calculate the contribution of secondaries to the radiation at a given point, data are needed on the probabilities of the various possible elementary and secondary processes. Such data are available, at least to the extent needed for shielding problems; they come either from experiments or from quantum-theoretical calculations. In any case, the solution to a specific problem is often expressed in terms of the "buildup factor," which is simply the ratio of the total radiation intensity to the intensity due to primary radiation alone (as calculated from narrow-beam data).

To cope with the tremendous mathematical difficulties of combining these many different probabilities, each of which varies with the energy of the photon and the nature of the medium, simplifying assumptions must be made. The aim is to choose these so that realistic problems can be approximated by a combination of several simplified cases.

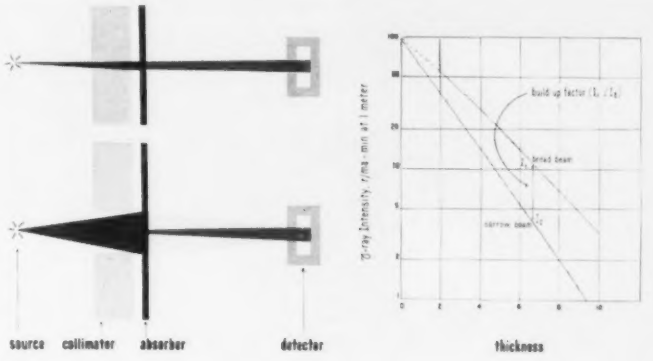
A monoenergetic source and an infinite homogeneous medium are perhaps the most obvious of such assumptions. The source is also assumed to have one or the other of four simplified geometries: point-collimated, with radiation from a single point in a single direction; point-isotropic, with uniform radiation in all directions from a single point; plane-collimated, with radiation emitted perpendicularly to the plane; or plane-isotropic, with uniform radiation in all directions from each point of a plane. The point-collimated or "gun" source is both the most fundamental (any other source is equivalent to a combination of gun sources) and the most difficult to compute; the first numerical results for such sources have only recently been obtained. Also, instead of studying the radiation flow at each point of the medium, one may try to find average or integrated values of the distribution—for example, the spectrum of secondaries integrated over the whole medium, or the distribution-in-direction of gammas degraded to a cer-

tain energy level regardless of their position with respect to the sources.

Moderate Penetration

A large proportion of the detailed information now available on gamma-ray penetration has been obtained from calculations based, directly or indirectly, on the polynomial method.[2] The labor required in calculating, by this method, the photon density and spectral and angular distributions is approximately the same for all depths up to 10 to 15 mean free paths. After that, the effort increases roughly as the cube of the depth, so that the method is unsuitable for great depths. For practical purposes, however, a depth of 12 mean free paths, for example, is fairly large, as in that distance the primary radiation loses all but 1 part in about 160,000 of its original intensity. The method is therefore suitable for nearly all shielding problems.

Comparison of narrow-beam gamma-ray attenuation with that of a broad (divergent) primary beam. In narrow-beam experiment (upper left), the detector receives only those photons that go straight through the absorber. The detector in the broad-beam experiment receives, in addition, photons that have been multiply scattered or that arise in secondary processes such as fluorescence. Graph shows that, for a given absorber thickness, broad-beam photons lose relatively less of their original intensity. The build-up factor (ratio of actual intensity to that which narrow-beam attenuation would produce alone) can be read directly from a semilogarithmic graph such as this.



Well adapted for use with high-speed automatic computers, the polynomial method is a seminumerical technique for solving the Boltzmann transport equation for an infinite medium. The original equation is reduced to a set of integral equations for the space moments of the photon density with energy as the sole independent variable. These equations are so interrelated that the successive space moments can be calculated by numerical integration of a finite number of the equations without any need for analytical approximations. The final solution can then be expressed in terms of the space moments and certain polynomial systems.

In one formulation, for example, the buildup factor for the density of photons of given energy and direction at a given depth is expressed as an infinite series in which each term is the product of three factors: a "weighted obliquity parameter" which depends on the space moments and the given data; a Laguerre polynomial with argument $\mu x / \rho$ (where ρ is the density of the medium); and a Legendre polynomial with the cosine of the direction angle as argument. Any desired degree of accuracy can be obtained by evaluating the series out to a sufficient number of terms. This, however, requires that a corresponding number of moments be calculated first. In practice, only a few of the moments are needed for results of relatively high accuracy.

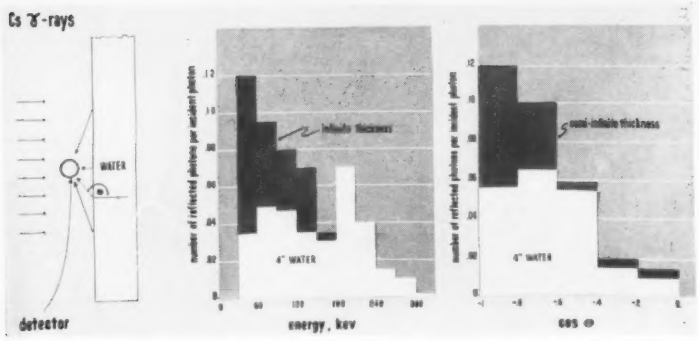
The method has been applied by Nuclear Development Associates and the Bureau in an extensive calculational program on the penetration of gamma rays in materials throughout the periodic table and for point-isotropic and plane-collimated sources. The materials investigated include pure Compton scatterer, H_2O, Al, Fe, Sn, W, Pb, and U. Recently, pilot calculations were started for a gun source; and, among others, a calculation is now under way for plane-isotropic sources which will provide data of direct use in fallout problems.

The raw results of the calculations are in the form of the weighted obliquity parameters mentioned above. These are calculated separately for different materials, source geometries, and source energies, and are tabulated for a series of secondary photon energies. Solutions to specific problems are then obtained by combining the appropriate raw data and tabulated values of the required polynomials.

Deep Penetration

In the study of penetration to depths greater than those accessible to the polynomial method, the Bureau's researches have led to a number of mathematical laws and workable methods of calculation.[3] Such investigations are not only indispensable for the treatment of unusually severe shielding problems, but they are useful for increasing confidence in numerical methods whose reliability tends to decrease as the depth of penetration increases.

Analysis shows that the intensity and spectral distribution of radiation at great distances from the source depend in a crucial way on whether the primary photons are above or below a certain energy, E_m, at which the narrow beam absorption coefficient for the given scattering medium has a minimum. That such a minimum exists for each medium has been known for some time. As the energy of primary photons is raised, the absorption coefficient falls steadily to a minimum at E_m and then rises again. Photons with energy, E_m, are thus more penetrating than those with either more or less energy. In the case of lead, for example, the en-



Results of Monte Carlo calculations of the reflection of 0.66-Mev gamma rays by water barriers of different thicknesses. Graphs give the distribution in energy (left) and direction (right) of the reflected photons, showing the strong influence of the barrier thickness on these distributions. Using a combination of theoretical analysis and advanced numerical techniques, the Monte Carlo method traces the individual histories of a random sample of photons on the basis of the probabilities with which the different possible elementary and secondary interactions with the medium occur.

ergy of the most penetrating radiation is 3.4 Mev. The values of E_m for a number of media are given in table 1.

The energy of a secondary photon cannot, of course, exceed that of the primary photon that gave rise to it. In fact, with the minor exception of those due to Rayleigh scattering, photons originating from interactions with the medium have energies less than those of the primary radiation. Hence, as radiation penetrates farther into a medium, the secondary photons fall to lower and lower energy levels. If the energy of the primary photons is less than E_m, this means that the secondaries become less and less penetrating, and their intensity decreases faster and faster. On the other hand, if the energy of the primaries is greater than E_m, the secondaries will gradually increase in penetrating power until their energy falls to E_m.

After reaching the value E_m, the energy of secondary photons will continue to fall as a result of further interactions. However, because photons of energy E_m have the maximum penetrating power, their further degradation in energy takes place more slowly. As a result, photons become partially "trapped" in the spectral region just below E_m, and the relative intensity of that part of the energy spectrum tends to increase.

Theoretical analysis indicates that at great depths the distribution in energy and direction of photons substantially below E_m in energy tends to become stabilized. That is, the proportion of secondary radiation with a given energy or moving in a given direction approaches constancy. For primary energies below E_m, the intensity of total radiation at great depths has been found to approximate a law given by the product of an exponential and a power function of the depth.

When the primary energy is above E_m, the manner in which the spectral distribution changes at great depths depends on the steady accumulation of secondaries with energies just below E_m. Those secondaries that are considerably below E_m will have a spectral distribution similar to that which occurs when the primaries are below E_m. Their intensity level, however, depends on the rate at which photons escape from the accumulation near E_m. The intensity of the total radiation under these conditions again follows a trend given by the product of power and exponential functions of the depth. In this case, however, the exponent of the exponential is nonlinear. Such fuctions have been worked out for a number of source geometries.

A Fourier-Laplace transform method for the detailed numerical calculation of gamma-ray intensities from plane sources or point-isotropic sources that makes use of the mathematical laws mentioned has been developed through the pilot stage. This technique has the advantage that the effort required does not increase rapidly with increasing depth of penetration.[5]

TABLE 1. *Energy, E_m, of the most penetrating photons in various media composed of single chemical elements*

Element	E_m	Element	E_m
	Mev		*Mev*
Be	94	Ca	13
B	70	Fe	9
C	56	Zn	7.6
N	46	Zr	5.4
O	39	Cd	4.4
F	33	Ba	3.9
Ne	29	W	3.5
Al	21	Pb	3.4
		U	3.3

Monte Carlo Experiments

Besides the methods described, much use has been made of Monte Carlo experiments.[4] Essentially mathematical rather than physical, this recently developed computational technique makes use of a numerical analogue of the situation under study. In the present program, these "experiments" have served to take the place of difficult physical measurements, check results of other methods, and study problems for which other methods were not available. They have been the principal method of attack on the study of radiation in the vicinity of boundaries between different media.

Though employing advanced refinements of numerical technique, the Monte Carlo experiment is, in principle at least, a straightforward approach. As applied to penetration problems, it calculates the separate histories of a number of photons with the help of chance devices analogous to roulette wheels. A photon is assumed to start with given energy and direction. A chance device, in which the probabilities of the possible outcomes correspond to the probabilities of the possible elementary interactions, is used to decide which of these processes occurs. If a Compton scattering is indicated, for example, another chance device is needed to decide the amount of deflection and energy loss; and it is necessary also to follow in the same way the course of the photon emitted when the excited atom returns to a lower energy state. The process is continued

until all the energy of the initial photon is dissipated. If a sufficient number of such individual histories is compiled, statistical analysis will then yield the desired information about intensities and distributions.

By taking advantage of certain theoretical considerations, the number of "case histories" needed has been reduced to within reasonable limits. Even so, the use of such a method is greatly facilitated by high-speed computers in which the functions of the chance devices may be performed by random or pseudo-random numbers. In seven Monte Carlo problems coded for SEAC earlier this year, for example, the computer circuits generate many millions of pseudorandom numbers.

Many problems have now been calculated by the method and the experience gained has suggested improvements in general coding technique, leading to greatly increased speed of computation. A special effort has been made to automatize the data processing, while at the same time permitting examination of the data at any stage of the operation.

Some of the problems that have been treated by the Monte Carlo method have technical applications in the field of reactor design, e. g., the penetration of beams of gamma radiation through shielding walls. Other problems are of radiological interest, e. g., the determination of the radiation dose delivered to various parts of the human body by an ingested gamma-ray source. Still other problems find applications in Civil Defense activities, e. g., the calculation of the radiation dose received by a man standing on the ground from a gamma-ray source overhead in the atmosphere. A physical experiment related to this problem is also in progress. In this experiment, the air-ground complex is replaced by a steel wool-steel complex. This substitution makes it possible to obtain the necessary measurements with precision under laboratory conditions instead of in large-scale field tests.

Further Research

As remarked above, the gamma-ray studies are part of a larger program whose aim is to acquire a firm knowledge of the phenomena that accompany the passage of ionizing radiations of all kinds through matter and of the elementary processes of interaction involved in these phenomena. It is hoped eventually to shift the emphasis toward a more detailed study of the elementary processes, but for the present there has been an intensification of the effort to develop and complete a number of numerical calculations on the basis of previously established general principles.

Much work has already been done on the problems of electron penetration for energies up to 40 Mev. Calculations based on the moment method have been made and promising new theoretical results have been obtained. All of these activities are to be continued; mass production of computational results is expected before the end of 1956. Application of the moment method to neutron penetration is contemplated.

Further calculations by the moment method are planned on gamma-ray propagation. These will be primarily for gun sources and, possibly, for media with plane boundaries. Monte Carlo calculations will continue, especially in the study of boundary effects. Tentative work on cascade shower calculations has been started; an early opportunity will be sought to continue this important project. Finally, an effort will be made to extend studies to higher energy levels and to study elementary interactions with many-particle systems.

[1] *A detailed discussion of penetration and diffusion problems for all ionizing radiations is being prepared by Bureau scientists for the Encyclopedia of Physics (Handbuch der Physik) edited by S. Flugge, Springer-Verlag, 1955. The state of research on gamma-ray penetration and diffusion through mid-1953 is summarized in* Gamma-ray attenuation *by U. Fano, Nucleonics* **11,** *8 and 9 (Aug. and Sept. 1953).*

[2] Penetration and diffusion of X-rays: calculation of spatial distribution by polynomial expansion, *by L. V. Spencer and U. Fano, J. Research NBS* **46,** *446 (1951) RP2213.*

[3] Penetration of X- and gamma-rays to extremely great depths, *by U. Fano, J. Research NBS* **51,** *95 (1953) RP2439.*

[4] Reflection and transmission of gamma radiation by barriers: Monte Carlo calculation by a collision-density method, *by M. J. Berger, J. Research NBS* **55,** *343 (1955) RP2640;* Reflections and transmission of gamma radiation by barriers: semianalytic Monte Carlo calculation, *by M. J. Berger and J. Doggett, J. Research NBS* **56,** *89 (1956) RP2653. A more specific application of Monte Carlo methods is contained in* Response function of thallium-activated sodium-iodide scintillation counters, *by M. J. Berger and J. Doggett, J. Research NBS* **56,** *355 (1956) RP2686.*

[5] Penetration and diffusion of X-rays: calculation of spatial distribution by semiasymptotic methods, *by L. V. Spencer, Phys. Rev.* **88,** *793 (1952).*

VERY-LOW-FREQUENCY SYMPOSIUM

COSPONSORING a very-low-frequency symposium January 23–25, 1957, will be the Denver-Boulder chapter of the IRE Professional Group on Antennas and Propagation and the NBS Boulder Laboratories.

Titled "Theoretical and Experimental Results in the Propagation and Radiation of Very-Low-Frequency Electromagnetic Waves (less than about 100 kc)," the symposium will be held at the Boulder Laboratories in Boulder, Colo.

In addition to technical papers, roundtable discussions will be included in the program. Among participants will be Owen Storey, Ottawa, Canada; K. G. Budden, Cavendish Laboratory, England; R. A. Helliwell, Stanford University; Morris M. Newman, Lightning and Transients Institute, Minneapolis, Minn.; W. Q. Crichlow, J. M. Watts, and others from the Boulder Laboratories; and staff members from the Navy Electronics Laboratory, Stanford University.

Papers in the VLF are being solicited now so that they may be prepublished. For this reason, authors are being requested to submit summaries for appraisal as soon as possible to Dr. J. R. Wait, chairman, Denver-Boulder PGAP Chapter, National Bureau of Standards, Boulder, Colo.

Suggestions regarding suitable topics for discussion are also being welcomed at this time.

Linear Thermal Expansion of Teflon

AS PART of its basic research program on the properties of materials, the Bureau has determined the linear thermal expansion of annealed polytetrafluoroethylene (Teflon) from −190° to +300° C.[1] This work, conducted by R. K. Kirby, also included a study of the effect of internal residual stresses on the expansion of Teflon and confirmed the presence of two first-order transitions at 20° and 30° C. With the data thus obtained, it is possible to calculate the dimensions that a Teflon product must have at room temperature in order that it will have the desired dimensions at the temperature of application.

Teflon is a thermoplastic resin made by polymerizing tetrafluoroethylene. It is being used in an increasing number of applications by industry because of its outstanding chemical and thermal stability, excellent electrical insulating properties, and low coefficient of friction. It has been used as gaskets, washers, and tubing by the chemical processing industry; high voltage and ultra-high-frequency insulators in electronic equipment; and as oil-free bearings in mechanical equipment.

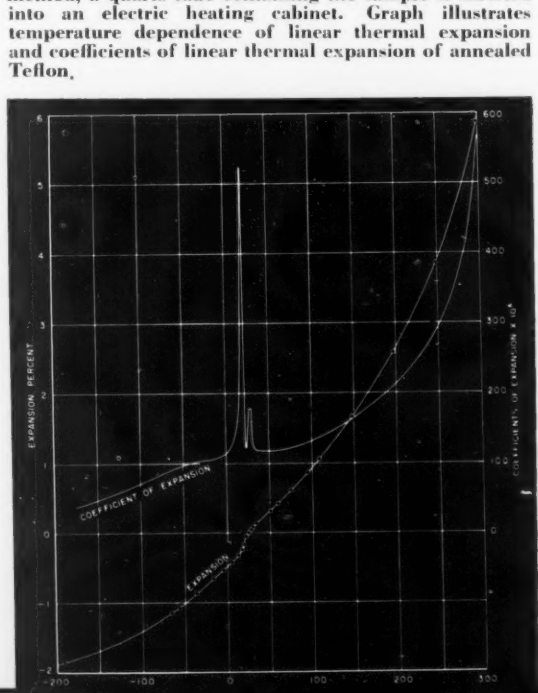
Because the long Teflon molecules are not straight over their entire length, the structure of Teflon is not completely crystalline. Above 330° C. Teflon is free of strain and has no crystalline structure. On cooling, Teflon starts to crystallize at about 325° C., and becomes opaque and waxy in appearance. On further cooling first-order transitions occur at 30° and 20° C.

The Bureau studied the thermal expansion of four samples of annealed Teflon. The fused-quartz tube and dial indicator method was used on three of the samples. In this method the sample is placed upright in a fused-quartz tube, closed at the bottom. A movable fused-quartz rod rests on top of the sample and transmits the differential change in length of the sample and fused-quartz to a dial indicator fastened to the top of the tube. The expansion of a fourth sample was measured with precision micrometric apparatus, which indicated that the small force exerted on the other samples by the quartz rod and dial indicator did not affect their expansion. Dry ice and liquid air provided the low temperatures, and an electric furnace and heating cabinet the high temperatures.

The coefficients of linear thermal expansion of annealed Teflon at 0° and 50° C were found to be 114×10^{-6} and $118\times10^{-6}/°$ C, respectively. The average coefficients of linear expansion from 0° to 25° C and from 25° to 50° C were 200×10^{-6} and $124\times10^{-6}/°$ C, respectively. The large differences between the "instantaneous" and average coefficients of expansion are caused by the transitions at 20° and 30° C. Repeated measurements indicate that the error of these coefficients is about $\pm3\times10^{-6}/°$ C.

The investigation also demonstrated that residual stresses affect the length and thermal expansion of Teflon. When Teflon is stretched or elongated, internal tensile stresses are set up that decrease its expansion. When compressive stresses are present in Teflon, it is

In determining the linear thermal expansion of annealed Teflon by the fused-quartz tube and dial indicator method, a quartz tube containing the sample is inserted into an electric heating cabinet. Graph illustrates temperature dependence of linear thermal expansion and coefficients of linear thermal expansion of annealed Teflon.



shorter and its expansion is increased. Annealing Teflon by heating to 350° C and cooling slowly removes the internal residual stresses.

[1] *For further technical details, see* Thermal expansion of polytetrafluoroethylene (Teflon) from −190° to +300° C, *by R. K. Kirby, J. Research NBS* **57,** *91 (1956) RP2696.*

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Technical News Bulletin, Volume **40,** No. 9, September 1956. 10 cents. Annual subscription $1.00

Basic Radio Propagation Predictions for January 1957. Three months in advance. CRPL 145. Issued September 1956. 10 cents. Annual subscription $1.00.

Journal of Research, volume **57,** *No. 3, September 1956. Single copies of the Journal, 60 cents. Single copies of Research Papers appearing in the Journal are not available for sale. The Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C., will reprint 100 or more copies of a Research Paper. Request for the purchase price should be mailed promptly to that office.*

Research Papers

RP2701. Techniques in high-resolution coincidence counting. George H. Minton.

RP2702. Chemical activity of gamma-irradiated polymethyl methacrylate. Leo A. Wall and Daniel W. Brown.

RP2703. Purification of substances by a process of freezing and fractional melting under equilibrium conditions. Augustus R. Glasgow, Jr., and Gaylon Ross.

RP2704. A high-voltage pulse generator and tests on an improved deflecting system of a cold-cathode oscillograph. Harold N. Cones.

RP2705. Dissociation constant of piperidinium ion from 0° to 50° C and related thermodynamic quantities. Roger G. Bates and Vincent E. Bower.

RP2706. Color evaluation in the cane sugar industry. Victor R. Deitz.

RP2707. System for classification of structurally related carbohydrates. Horace S. Isbell.

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C576. Automotive antifreezes. Frank L. Howard, Donald B. Brooks, and Ronald E. Streets. 15 cents.

C577. Energy loss and range of electrons and positrons. Ann T. Nelms. 30 cents.

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A. V. ASTIN, *Director*

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